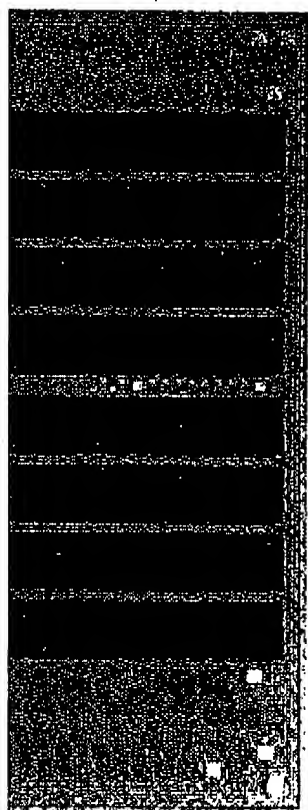


**EXHIBIT A**

Excerpts from Streetman, Ben G., Solid State Electronic Device, Prentice-Hall, Inc., 1980, page 67.

Exhibit in Support of Response – NVX-0015C1

Received from <408 977 0174 > at 10/11/02 2:10:58 PM [Eastern Daylight Time]



# SOLID STATE ELECTRONIC DEVICES

**second edition**

**BEN G. STREETMAN**

**Department of Electrical Engineering  
The University of Texas at Austin**

Special conditions

1)  $d^2 \sigma^2 / dx^2 = 0$  local minimum  
 2)  $d\sigma^2/dx = 0$  remains same  
 3)  $d^2 \sigma^2 / dx^2 > 0$  local minimum  
 4)  $d^2 \sigma^2 / dx^2 < 0$  local maximum

$$b) \rho = D_p \frac{\partial^2 p}{\partial x^2} - \frac{\partial p}{\partial t} \quad (1)$$

Rate of diff. =  $\frac{1}{\tau} = \frac{1}{\tau_1} + \frac{1}{\tau_2} + \dots$

2/1/77 : 1. 5

c)  $d\sigma_p/dt = -\sigma_p/r$

c)  $d\sigma_p/dt = -1.17 \times 10^{-26} \text{ cm}^2$   
 d)  $d\sigma_p/dt = 0$  no concentration of particles  
 e)  $d\sigma_p/dt = 0$  the equilibrium

Lowest of certain  
concentration

$$z_i = \sqrt{N_i} \mu_i e^{-b_i/10}$$

A. B. G. Zander

quit chip employs charge-coupled This is achieved with 16 memories of up (0.27 cm<sup>2</sup>). An additional 4 k-bit als, and peripheral input-output and modern integrated circuit technology which cannot be understood without evices. The purpose of this book is to er understand and use the solid state y of Texas Instruments, Inc.)

**PRENTICE-HALL, INC., Englewood Cliffs, New Jersey 07632**

*Library of Congress Cataloging in Publication Data*

STURTEMAN, BEN G

Solid state electronic devices.

Bibliography: p.

Includes index.

1. Semiconductors. I. Title.

TK7871.85.877 1979

621.3815'2

79-16994

ISBN 0-13-822171-5

Editorial/production supervision and design by Virginia Rubens

Cover design by Edsal Enterprises

Manufacturing buyer: Gordon Osbourne

Drawings by Scientific Illustrators, Champaign, Ill.

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Printed in the United States of America

10 9 8.

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PRENTICE-HALL OF AUSTRALIA PTY. LIMITED, Sydney  
PRENTICE-HALL OF CANADA, LTD., Toronto  
PRENTICE-HALL OF INDIA PRIVATE LIMITED, New Delhi  
PRENTICE-HALL OF JAPAN, INC., Tokyo  
PRENTICE-HALL OF SOUTHEAST ASIA PTE. LTD., Singapore  
WHITEHALL BOOKS LIMITED, Wellington, New Zealand

*Preface xv***1 Crystal Properties a**

- 1.1 Semiconductor Mate
- 1.2 Crystal Lattices
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**2 Atoms and Electron**

- 2.1 Introduction to Physi
- 2.2 Experimental Observ
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When an electron is taken away from its position in the bond, it is free to move about in the lattice, a conduction electron. The empty bond (hole) is left behind. The energy level of the electron is the band gap energy  $E_g$ . This model helps in understanding the mechanism of EHP creation, but the energy band model is not suitable for quantitative calculation. One "bond" model is that the free electron and hole are spread out over several lattice spacings, and their positions are determined mechanically by probability distribution.

When electron-hole pairs are created in pairs, the conduction electron concentration ( $n$  per  $\text{cm}^3$ ) is equal to the concentration of holes ( $p$  per  $\text{cm}^3$ ). Each of these intrinsic carrier concentrations is denoted as  $n_i$ . Thus for intrinsic material,

$$n = p = n_i \quad (3.1)$$

For a certain concentration of electron-hole pairs, the carrier concentration is maintained, there is a balance between the same rate at which they are generated and the rate at which they recombine. An electron in the conduction band makes a transition to an empty state (hole) in the valence band. Let  $g$  denote the generation rate of EHP's as  $r_i$ , and let  $r_r$  denote the recombination rate as  $r_r$ , equilibrium requires that

$$r_i = r_r \quad (3.2)$$

which is independent of temperature. For example,  $g_i(T)$  increases with temperature, and a new carrier concentration  $n_i$  is established. The generation rate  $r_i(T)$  just balances generation rate  $r_r(T)$  that the rate of recombination of electron-hole pairs is equal to the equilibrium concentration of electron-hole pairs.

$$n_i p_i = n_i^2 = g_i \quad (3.3)$$

which is a proportionality which depends on the particular material. We shall discuss the calculation of  $n_i$  in Section 3.3.3; recombination probability is given in Section 4.

When carriers are generated thermally, it is possible to control the carrier concentration by purposely introducing impurities. Doping, is the most common technique.

The conductivity of semiconductors. By doping, a crystal can be made so that it has a predominance of either electrons or holes. Thus there are two types of doped semiconductors, n-type (mostly electrons) and p-type (mostly holes). When a crystal is doped such that the equilibrium carrier concentrations  $n_0$  and  $p_0$  are different from the intrinsic carrier concentration  $n_i$ , the material is said to be *extrinsic*.

When impurities or lattice defects are introduced into an otherwise pure crystal, additional levels are created in the energy band structure, within the band gap. For example, an impurity from column V of the periodic table (P, As, and Sb) introduces an energy level very near the conduction band in Ge or Si. This level is filled with electrons at 0°K, and little thermal energy is required to excite these electrons to the conduction band (Fig. 3-11). Thus at about 50–100°K virtually all of the electrons in the impurity level are "donated" to the conduction band. Such an impurity level is called a *donor level*, and the column V impurities in Ge or Si are called *donor impurities*. From Fig. 3-11 we note that material doped with donor impurities can have a considerable concentration of electrons in the conduction band, even when the temperature is too low for the intrinsic EHP concentration to be appreciable. Thus semiconductors doped with a signif-

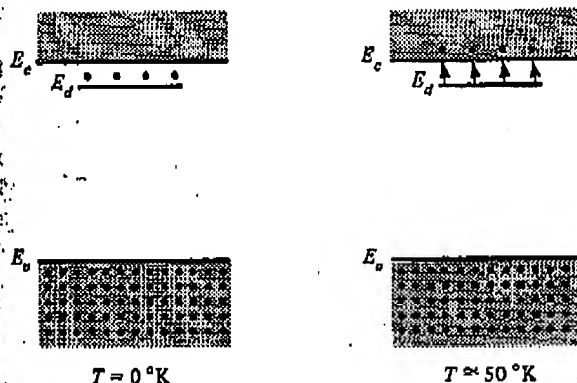


Figure 3-11. Donation of electrons from a donor level to the conduction band.

number of donor atoms will have  $n_0 \gg (n_i, p_0)$  at room temperature. This is called *n-type material*.

Atoms from column III (B, Al, Ga, and In) introduce impurity levels in Ge or Si near the valence band. These levels are empty of electrons at 0°K (Fig. 3-12). At low temperatures, enough thermal energy is available to excite electrons from the valence band into the impurity level, leaving holes in the valence band. Since this type of impurity level "accepts"